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THE ANALYSIS OF WORK SHIFT PATTERNS AND RISK OF FATIGUE IN AIRCRAFT MAINTENANCE PERSONNEL: A CASE STUDY

Summary. In response to the COVID-19 pandemic in 2020, PT. XYZ, the biggest aircraft maintenance, repair, and overhaul (MRO) company in Indonesia, implemented a new shift pattern for line-maintenance personnel. The new shift pattern allows maintenance personnel to have fewer working hours per day (7-hour shifts) in more shift varieties for 5 consecutive days. Maintenance personnel will have 2-morning shifts, 1-noon shift, and 2-night shifts followed by 3 rest days. This study aims to explore the risk of fatigue caused by the newly implemented shift pattern. Data were collected through electronic questionnaires from a total of 303 respondents. This study found that at the time of the survey, many respondents (78 of 303, 26%) felt tired and had difficulty concentrating, regardless of the shift they were in. Based on the duty time, the highest scores of level 6 (tired, difficult to concentrate) were discovered on night shift day 5. This result shows that although the organization had provided the maintenance personnel with the opportunity to obtain sleep during rest days, tiredness and fatigue were still experienced by the aircraft maintenance personnel. This study recommends necessary actions to be taken to prevent fatigue, especially from the noon shift afterwards, where fatigue level is increasing, and alertness level is decreasing.
Keywords: fatigue, work shift patterns, aircraft maintenance, risk analysis

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1. INTRODUCTION

In November 2020, a transition of the previous 2-2 shift pattern to a 5-3 new shift pattern was carried out at PT. XYZ. The previous 2-2 shift pattern allows line-maintenance personnel to have a 12-hour shift which starts in the morning on day 1 and starts in the evening on day 2. Following that, maintenance personnel are supposed to have 2 rest days afterwards.

The new 5-3 shift pattern, however, allows maintenance personnel to have fewer working hours per day (7-hour shifts) in more shift varieties. The morning shift on days 1 and 2 starts at 6 AM to 8 AM, the noon shift starts at 2 PM on day 3, and the night shift on days 4 and 5 starts at 9 PM to 11 PM. Maintenance personnel will then have 3 consecutive rest days. These resting days were intended to be used by the maintenance personnel to recover from their previous working days. However, the changing shift work may cause disrupted sleep, which could result in health and safety issues and the risk of fatigue.

Based on previous research [1], sleepiness and fatigue associated with a sleep debt are cumulative. Losing an hour of sleep every other night for a week could result in situations that impair performance. Much research has focused on flight crew shift patterns and their ramifications, but there is currently little evidence on how work patterns may affect aviation maintenance personnel's sleep and the problems that may result. Thus, this research aims to analyse the effect of changing shift patterns toward the risk of fatigue of aviation maintenance personnel.

2. LITERATURE REVIEW

2.1 Fatigue

Referring to ICAO [2], fatigue is a physiological state of reduced mental or physical performance capability resulting from sleep loss, extended wakefulness, circadian phase, and/or workload (mental and/or physical activity) that can impair a person’s alertness and ability to adequately perform safety-related operational duties. The chief cause of fatigue is not having obtained adequate rest or recovery from previous activities. Research conducted by Transport Canada [3] stated that there are three major categories of fatigue consequences – physical (for example, abruptly nodding off for a few seconds, called a microsleep), mental (for example, lapses in attention) and emotional (for example, irritability).

2.2 Managing Fatigue

Fatigue management is a crucial aspect of safety management since it is a significant and preventable element in transportation incidents or accidents. Sometimes, organizations and regulators manage fatigue indirectly through prescriptive limits on work hours, often because it is seen as the only available option [4]. However, a given amount of break from work does not necessarily provide a given level of fatigue recovery as the length of the break is not the main factor but rather the amount and quality of sleep obtained [5]. Both work and non-work factors can affect sleep [6]. Work-related factors such as shift length, work type, workload, work environment, and breaks within a shift can affect the quantity of sleep and time awake acquired in a 24-hour period. Also, non-work-related issues, such as sleep disorders, family duties, social and leisure activities, and mental stress, can impact the amount and quality of sleep people get. These factors can also influence how long people stay up, which can lead to fatigue. The graph below depicts the association between these variables.

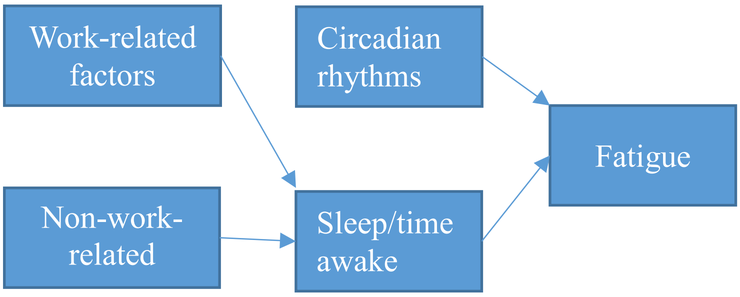

Fig. 1. Factors affecting fatigue

FAA [7] issued Advisory Circular AC 120-115 stating that the causes of fatigue in aviation maintenance are shared by the organization and by the maintenance personnel. It is because both the organization and maintenance personnel have factors that they can control. For example, the organization can control the start time and duration of a shift, schedule changes, rotation of shift schedules, sufficient breaks for employees, and workplace environment such as lighting, temperatures, etc. On the other hand, maintenance personnel also can control the amount of sleep they obtain during break days, quality of sleep, and activities outside work. To be able to take responsibility for themselves, maintenance personnel must have a thorough grasp of the causes and effects of fatigue [8]. Conceptually, managing fatigue can help organizations identify hazards related to fatigue and mitigate any associated risks beforehand.

The ICAO SARPs [2] require three types of hazard identification, which are predictive, proactive, and reactive. In predictive hazard identification, fatigue could be discovered by reviewing anticipated work schedules (rosters) and considering the elements known to affect sleep and fatigue. Then in proactive hazard identification, fatigue can be identified by monitoring the tiredness level in current operations. Meanwhile, fatigue hazard identified by examining the role of fatigue in safety reports and past events is classified in reactive hazard identification.

Aligning with ICAO, Transport Canada applied Reason's [9] principle of hazard identification in Safety Management System (SMS) to Fatigue Risk Management System (FRMS).

There are five major levels of control for managing fatigue risk that an organization can follow:

- Level 1 (organizational): work schedule gives employees adequate opportunity to sleep,
- Level 2 (individual): personal responsibilities of employees to actually get sufficient sleep,
- Level 3 (behavioral): monitoring or systems to detect fatigue symptoms,
- Level 4 (error): strategies to prevent workplace fatigue from causing errors or mishaps,
- Level 5 (incident): identifying the role of fatigue in workplace errors or incidents.

A defense system around each level is necessary to support a successful fatigue risk management system.

Many studies use the Samn-Perelli fatigue scale and other objective tools to measure pilot fatigue levels at work [10–15]; however, none of these studies has used aircraft maintenance personnel as the target to survey their fatigue levels under the various shift schedules.

3. METHODOLOGY

This research used the Samn-Perelli Status Check, Fatigue Likelihood Score, and Individual Fatigue Likelihood in determining the risk of fatigue for the newly implemented shift pattern. Data were collected through electronic questionnaires. The questionnaire consists of 6 questions that were sent to a total of 303 aviation maintenance personnel distributed in each work shift.

3.1 Samn-Perelli Status Check

The Samn-Perelli Status Check is a 7-point scale that subjectively measures the respondent's level of fatigue at that moment in time [16]. Possible scores range from 1 ("fully alert, wide awake") to 7 ("completely exhausted, unable to function effectively"). This scale was initially designed to test pilot fatigue and alertness before takeoff.

3.2 Fatigue Likelihood Score (based on work schedules)

The primary goal of reviewing work schedules is to understand the possible effects that particular hours of work will have on sleep opportunities, in addition to making sure that they adhere to industry standards and other regulations. In the context of a Fatigue Risk Management System (FRMS), the company is responsible for ensuring that appropriate opportunity for sleep is provided between work shifts. It is the obligation of the maintenance employees to take advantage of the available possibilities for recovery sleep.

Tab. 1

Fatigue Likelihood Scoring Matrix for Work Schedule

Score	0	1	2	4	8
Total hours per 7 days (hours)	< 36	36.1 – 43.9	44 – 47.9	48 – 54.9	55+
Maximum shift duration (hours)	< 8	8.1 – 9.9	10 – 11.9	12 – 13.9	14+
Minimum short break duration (hours)	> 16	15.9 – 13	12.9 – 10	9.9 – 8	< 8
Maximum night work per 7 days (hours)	0	0.1 – 8	8.1 – 16	16.1 – 24	> 24
Long break frequency (days)	> 1 in 7	< 1 in 7	< 1 in 14	<1 in 21	< 1 in 28

Referring to Transport Canada [3], this is level 1 control for managing fatigue.

To assess sleep opportunity and potential fatigue, the following questions should be answered:

1. Hours worked per seven-day period
2. Maximum shift length
3. Minimum length of time off between shifts
4. Hours worked on night shift per 7 days
5. Long break frequency

Table 1 shows the scoring matrix of the Fatigue Likelihood Score. Based on Table 1, an ordinary 9 to 5 working hours (5 days consecutively) would produce a score of zero. On the other hand, a work schedule of seven 12-hour night shifts, followed by seven days off, would produce a score of 21, which would be considered high. This approach is further described in Figure 2.

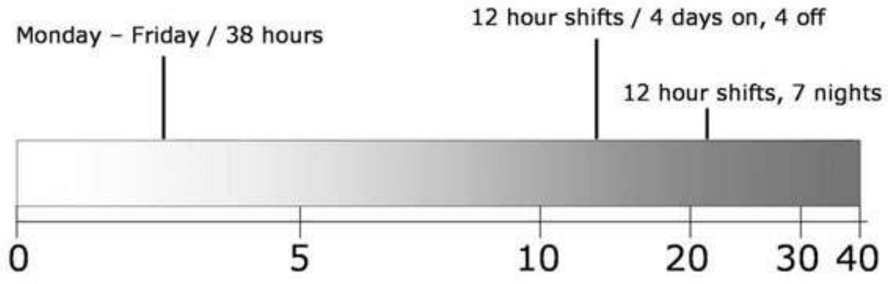

Fig. 2. Examples of work schedules scored

3.3 Individual Fatigue Likelihood (based on time asleep and awake)

Level 2 control for managing fatigue is to make sure maintenance personnel actually have sufficient sleep. This level aims at the individual level rather than the organizational level. The score calculation and decision tree are shown in Tables 2 and 3.

Tab. 2

Individual fatigue likelihood scoring

Prior sleep/wake factor	Threshold value	Scoring
X (sleep in prior 24 hours)	5 hours	Add 4 points for every hour below threshold
Y (sleep in prior 48 hours)	12 hours	Add 2 points for each hour below threshold
Z (time awake since last sleep)	Y	Add 1 point for each hour of wakefulness greater than Y

Tab. 3

Individual fatigue likelihood score, risk level, and approved controls

Individual Fatigue Score	Risk Level	Approved Controls
Zero	Acceptable	No additional controls are necessary except in the presence of higher-level indicators of fatigue (that is, symptoms, errors, or incidents)
1-4	Minor	Inform the line supervisor and document it in the daily logbook. Self-monitor for fatigue-related symptoms, and apply individual controls such as strategic use of

		caffeine, task rotation, working in pairs, and additional rest breaks
5-8	Moderate	Inform the local manager and document it in a fatigue report. Implement additional fatigue controls such as task reallocation, napping, and increased level of peer and supervisory monitoring
9+	Significant	Call the manager before driving to work. Document in a fatigue report on the next work shift. Do not engage in safety-critical tasks (including driving to work), and do not return to work until sufficiently rested as per sleep/time awake rules

4. RESULTS AND DISCUSSION

This survey was conducted on 3 units (A, B, C) which were directly affected by the New Patterns Shift 5-3. The distribution of the number of surveys can be seen in the demography below:

Units of Respondents

A total of 303 respondents were separated into 3 units. A unit consisting of 216 employees sent 61 responses, achieving 28.2% of respondents. Then C unit totaling 149 employees, sent 66 responses, achieving 44.2% of respondents. While B unit comprising 276 employees sent 176 responses, achieving 63.7% of respondents.

Shifts of Respondents

Based on shifts carried out in these 3 units, it was divided into 5 parts of shift, namely morning shift 1 (P1), morning shift 2 (P2), noon (S), night shift 1 (M1), and night shift 2 (M2). The response results obtained at the P1 shift were 54 or 18% of respondents; on the P2 shift, 38 or 12% of respondents; on the S shift, 60 or 20% of respondents; on the M1 shift, 45 or 15% of respondents; and the M2 shift, 106 or 35% of respondents (Figure 3).

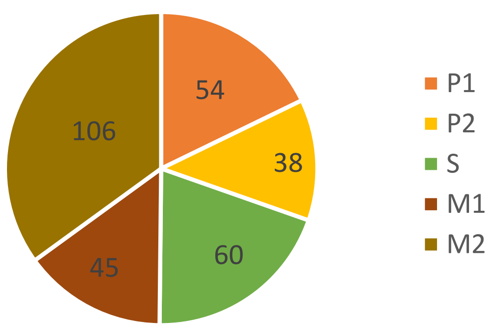

Fig. 3. Work shifts of respondents

4.1 Survey Result

4.1.1 Samn-Perelli Status Check

Survey question number 4 is a simplified version of the Samn-Perelli Checklist, which asked respondents to rate their level of fatigue at the time the survey was taken. As illustrated in Figure 4, many respondents (78 out of 303, 26%) felt tired and had difficulty concentrating, regardless of the shift they were in. Further, 20% of the respondents felt extremely exhausted and unable to concentrate (60 out of 303), followed by 19% who felt moderately tired (57 out of 303).

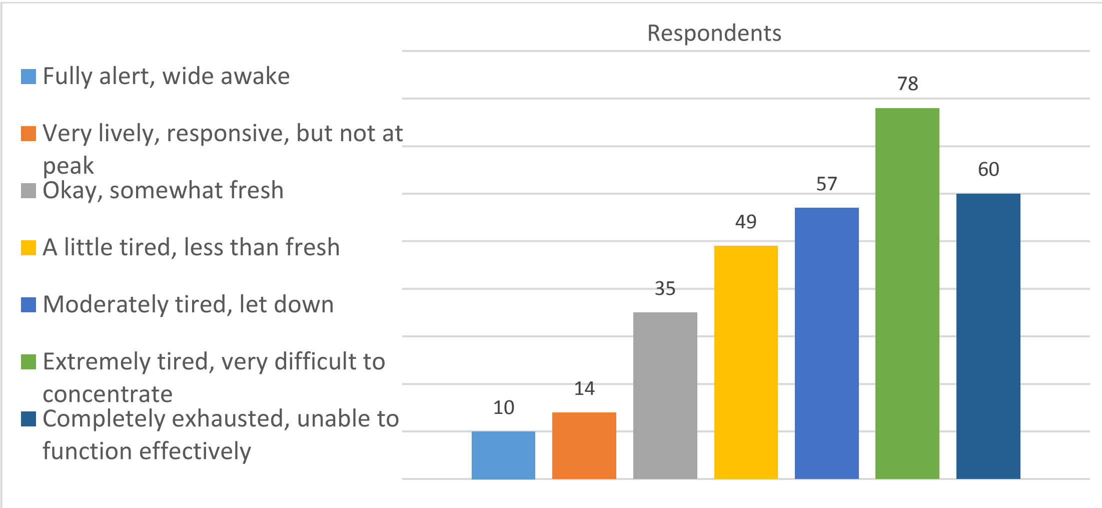

Fig. 4. Respondents' Samn-Perelli status results

Figure 5 shows an increasing fatigue level of the current condition during each shift. The numbers marked 'X' in the middle of the boxes are the average scores (mean) for each shift, and the numbers with lines inside the boxes are the median of each shift.

Most respondents on morning shift day 1 (P1) felt "okay, somewhat fresh" or equal to level 3. This average score then increases for respondents on morning day 2 (P2) to level 4 ("a little tired, less than fresh"). On the noon shift day 3 (S) and night shift day 4 (M1), many respondents felt "Moderately tired, let down" or equal to level 5. Data on night shift day 5 (M2) has the highest average score (level 6), which stands for "extremely tired, very difficult to concentrate".

This figure supports the Circadian Rhythms body clock, where human alertness tends to be higher, and sleepiness levels are lower at 3 PM than at 3 AM [17–19]. Aircraft maintenance personnel performance reaches its minimum in the early dawn, referred to as the 'window of circadian low'[20]. The circadian body clock does not adapt fully to altered schedules such as rotating shifts or night work, although each maintenance personnel have more break time between shifts.

4.1.2 Fatigue Likelihood Scores

Every maintenance personnel experienced the same new shift pattern; therefore, it could be assumed that the company gives equal opportunity for maintenance employees to rest. This fatigue likelihood score assesses whether the current schedule provides the maintenance personnel with sufficient sleep opportunities to reduce the risk of fatigue.

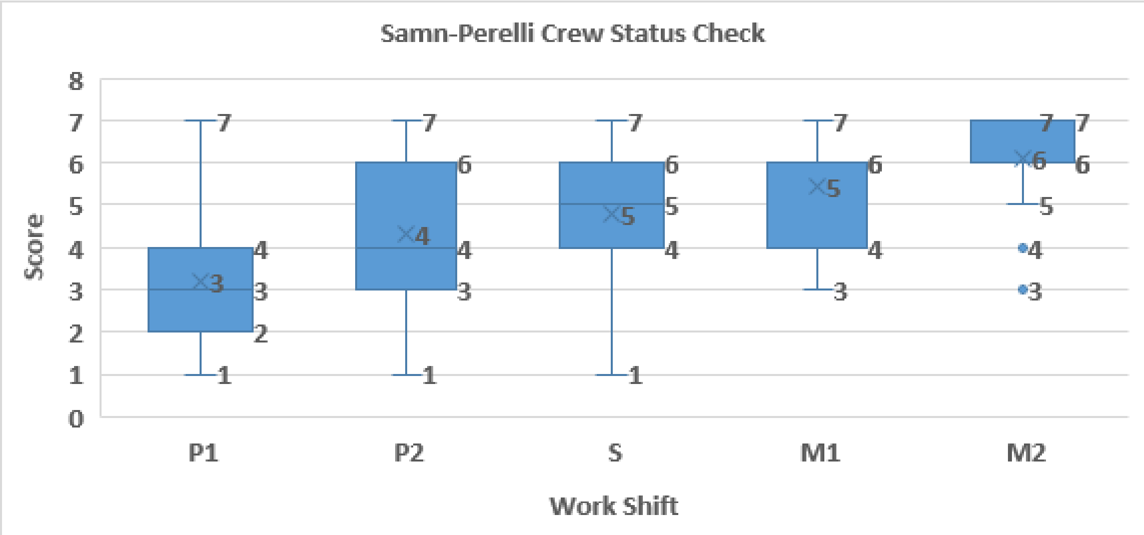

Fig. 5. Samn-Perelli Status Check

Assuming each maintenance personnel have 5 working days in which each day comprises 7 working hours, therefore, the total hours per 7 days is 35 hours (score 0).

The maximum shift duration of each shift is ideally 7 working hours, which also produces a 0 score.

The time between shifts ranges between 16 to 23 hours; therefore, the score for minimum short break duration is also 0.

There are 2 consecutive night shifts of this new shift pattern. This produces a maximum score of 2 for maximum night work per 7 days.

The break frequency is 2 in 7 days, which also contributes to 0 scores for this calculation.

In total, the fatigue likelihood score of this new pattern ranges between 0 to 2.

Based on the theory, the new shift pattern of 5-3 in line with the maintenance department is still considered a low-risk category.

4.1.3 Individual Fatigue Likelihood Scores

Figure 6 describes the individual fatigue likelihood score based on the FRMS Survey question numbers 5, 6 and 7. The numbers marked ‘X’ in the middle of the boxes are the average scores (mean) for each shift, and the numbers with lines inside the boxes are the median of each shift.

Based on the data survey, individual fatigue likelihood scores are distributed in moderate risk levels. Most respondents on morning day 1 have an average total individual fatigue score of 6, which fall into the moderate risk level. Respondents who filled out the survey on morning day 2 duty have a higher individual fatigue likelihood score (8) compared to respondents on the morning day 1 shift. However, this is also categorized as a moderate risk level.

On the other hand, respondents with duty on the noon shift have a smaller average total individual fatigue score, which is score 6 and equals to moderate risk level. The average total individual fatigue score rises for respondents who participated in the night shift day 4 (total score of 7, moderate risk level). And the highest average total individual fatigue score (score 9) was discovered in respondents whose duty is on night shift day 5. This average score is considered a significant risk level and should be eliminated immediately.

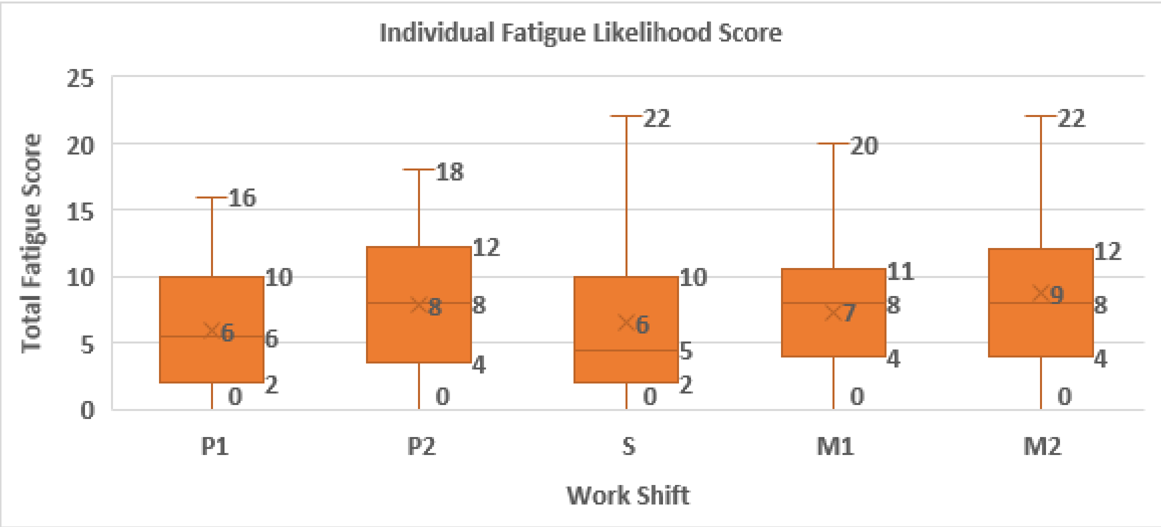

Fig. 6. Individual fatigue likelihood score results

From the results and analysis, it is known that at the time of the survey, many respondents (78 out of 303, 26%) felt tired and had difficulty concentrating, regardless of the shift they were in. Then 20% of the respondents felt extremely exhausted and unable to concentrate (60 out of 303), followed by 19% feeling moderately tired (57 out of 303). Based on the duty time, the highest scores of level 6 (tired, difficult to concentrate) were discovered on the night shift day 5, followed by level 5 (moderately tired) on night shift day 4 and noon shift. This result shows that necessary actions are required to be taken to prevent fatigue, especially from the noon shift afterwards, where fatigue levels are increasing, and alertness levels are decreasing.

Nevertheless, the fatigue likelihood score shows the contrary. This method of assessment is showing level 1 fatigue control; ensure organizations give a sufficient day off time for maintenance personnel to sleep. The risk level of the new shift pattern is considered low risk based on hours worked per seven-day period, maximum shift length, minimum length of time off between shifts, hours worked on night shift per seven-day, and long break frequency. There was no significant case resulting in a higher score of fatigue likelihood. This is due to the assumptions of no overwork during shifts, maximum of 16 hours of night shifts per seven-day, and no consideration of the circadian rhythm and its effect. Chang et al. [21] revealed that people adapt their work-rest cycles based on their work days, which prevents fatigue levels from increasing over successive work days of the same schedule since employees may plan their work days ahead of time. However, uneven morning and afternoon work hours could result in excessive weariness with particular shift types.

Thus, the calculation of fatigue likelihood scores should be detailed in the next control, which is level 2; the quality of sleep obtained by the maintenance personnel. Individual fatigue likelihood score describes whether the sleep obtained during off-duty time is good quality sleep. From the result of the Individual Fatigue Likelihood Scores, it is known that the respondents on the night shift day 2 experienced significant fatigue (score 9), whereas, on other shifts, respondents underwent moderate fatigue ranging from a total score of 5 to 8. It can be concluded that although an organization has provided the maintenance personnel with the opportunity to obtain sleep during rest days, it does not necessarily mean that the maintenance personnel will actually have good quality sleep to recover from the fatigue they are experiencing. Although the break time between each shift is longer than 12 hours; however, regarding the Circadian Rhythms, it might be difficult for the maintenance personnel to sleep when the body clock tends to be on the peak level of alertness.

Based on the survey results and analysis, it is suggested that an organization should have sufficient fatigue controls in place to reduce the likelihood of fatigue-related incidents. This can be done by evaluating the possibility of overwork in each shift due to the unavailability of a supporting system (for example, tools, equipment, and next-shift personnel), which could contribute to a higher fatigue likelihood score. It is necessary to review the new shift pattern of 5-3 in the Line Maintenance Department and focus more on the actual working hours of the maintenance personnel. Manpower planning corresponding to daily load should be considered to minimize the gap between each shift.

Moreover, fatigue awareness training and promotion need to be performed to enhance the knowledge of fatigue and the importance of having good quality sleep. Managing fatigue responsibility is shared between the organization and the maintenance personnel as an individual. Therefore, the maintenance personnel should be better aware of the fatigue conditions they experience. Periodic promotion events such as webinars, email publications, and banners are favorable as a fresh start.

5. CONCLUSION

The new 5-3 work shift pattern allows maintenance personnel to have fewer working hours per day (7-hour shifts) in more shift varieties. The morning shift on days 1 and 2 starts at 6 AM to 8 AM, the noon shift at 2 PM on day 3, and the night shift on days 4 and 5 starts at 9 PM to 11 PM. Subsequently, the maintenance personnel will then have 3 consecutive rest days.

Based on the Samn-Perelli Status Check, fatigue likelihood scores, and individual fatigue likelihood scores, this study finds that at the time of the survey, many respondents (78 out of 303, 26%) felt tired and had difficulty concentrating, regardless of the shift they were in. Based on the duty time, the highest score of level 6 (tired, difficult to concentrate) was discovered on night shift day 5. This result shows that necessary actions are required to be taken to prevent fatigue and further implications on safety, especially from the noon shift afterwards, where fatigue levels are increasing, and alertness levels are decreasing.

Consequently, this study recommends several actions to be taken. The first action is to provide sufficient fatigue controls in place to reduce the likelihood of fatigue-related accidents. This can be done by evaluating the possibility of overwork in each shift due to the unavailability of a supporting system, providing a better rest area and environment. The second action is to consider the importance of the circadian rhythm and break time between shifts in future scheduling. The break time between scheduling should ensure that the aircraft maintenance personnel have sufficient time to sleep or rest during their off-duty time. Finally, the third action is to offer fatigue awareness training and promotion to enhance maintenance personnel’s knowledge of fatigue and the importance of having good quality sleep.

Future research should consider the effect of work shifts on aircraft maintenance personnel's work performance. Measurements or techniques that can capture and evaluate the impact of sleep quality obtained by the maintenance personnel, break time, and work performance, should be explored.

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